CSC 4103 - Operating Systems
Fall 2009

Lecture - X
Deadlocks - I

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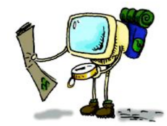
Roadmap

- Deadlocks
  - Deadlock Characterization
  - Deadlock Detection
    - Resource Allocation Graphs
- Classic Problems of Synchronization
  - Bounded Buffer

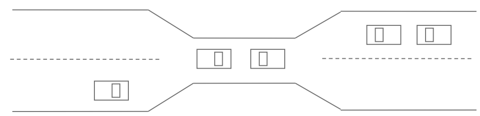


The Deadlock Problem

- A set of blocked processes each holding a resource and waiting to acquire a resource held by another process in the set.
- Example
  - System has 2 disk drives.
  - P_1 and P_2 each hold one disk drive and each needs another one.
- Example
  - semaphores *A* and *B*, initialized to 1

P_0	P_1
wait (A);	*wait(B)*
wait (B);	*wait(A)*

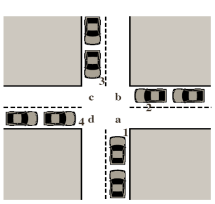
Bridge Crossing Example



- Traffic only in one direction.
- Each section of a bridge can be viewed as a resource.
- If a deadlock occurs, it can be resolved if one car backs up (preempt resources and rollback).
- Several cars may have to be backed up if a deadlock occurs.

Deadlock vs Starvation

- Deadlock - two or more processes are waiting indefinitely for an event that can be caused by only one of the waiting processes



(a) Deadlock possible

- Starvation - indefinite blocking. A process may never be removed from the semaphore queue in which it is suspended.

Deadlock Characterization

Deadlock can arise if four conditions hold simultaneously.

1. **Mutual exclusion:** nonshared resources; only one process at a time can use a specific resource
2. **Hold and wait:** a process holding at least one resource is waiting to acquire additional resources held by other processes
3. **No preemption:** a resource can be released only voluntarily by the process holding it, after that process has completed its task

Deadlock Characterization (cont.)

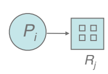
Deadlock can arise if four conditions hold simultaneously.

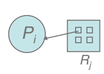
4. Circular wait: there exists a set $\{P_0, P_1, \ldots, P_0\}$ of waiting processes such that P_0 is waiting for a resource that is held by P_1, P_1 is waiting for a resource that is held by
$P_2, \ldots, P_{n-1}$ is waiting for a resource that is held by
P_n, and P_n is waiting for a resource that is held by P_0.

Resource-Allocation Graph

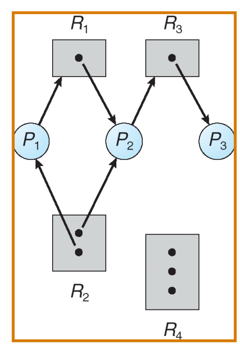
- Used to describe deadlocks
- Consists of a set of vertices *V* and a set of edges *E*.
- V is partitioned into two types:
  - $P = \{P_1, P_2, \ldots, P_n\}$, the set consisting of all the processes in the system.
  - $R = \{R_1, R_2, \ldots, R_m\}$, the set consisting of all resource types in the system.
- P requests R – directed edge $P_1 \rightarrow R_j$
- R is assigned to P – directed edge $R_j \rightarrow P_i$

Resource-Allocation Graph (Cont.)

- Process 
- Resource Type with 4 instances 
- P_i requests instance of R_j 

- P_i is holding an instance of R_j 

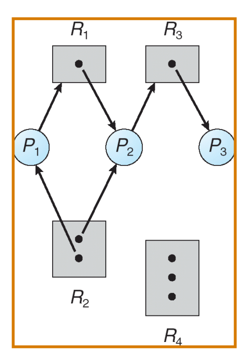
Example of a Resource Allocation Graph



Basic Facts

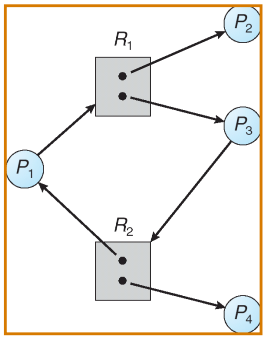
- If graph contains no cycles ⇒ no deadlock.
- If graph contains a cycle ⇒ there may be a deadlock
  - if only one instance per resource type, then deadlock.
  - if several instances per resource type, possibility of deadlock.

Resource Allocation Graph - Example 1



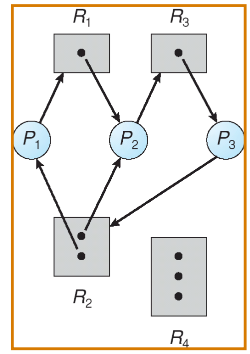
➔ No Cycle, no Deadlock

Resource Allocation Graph – Example 2



→ Cycle, but no Deadlock

Resource Allocation Graph – example 3



→ Deadlock

Which Processes deadlocked?

→ P1 & P2 & P3

Exercise

In the code below, three processes are competing for six resources labeled A to F.

a. Using a resource allocation graph (Silberschatz pp.249-251) show the possiblity of a deadlock in this implementation.

```
void P0()
{
  while (true) {
    get(A);
    get(B);
    get(C);
    // critical region:
    // use A, B, C
    release(A);
    release(B);
    release(C);
  }
}
```

```
void P1()
{
  while (true) {
    get(D);
    get(E);
    get(B);
    // critical region:
    // use D, E, B
    release(D);
    release(E);
    release(B);
  }
}
```

```
void P2()
{
  while (true) {
    get(C);
    get(F);
    get(D);
    // critical region:
    // use C, F, D
    release(C);
    release(F);
    release(D);
  }
}
```


Rule of Thumb

- A cycle in the resource allocation graph
  - Is a necessary condition for a deadlock
  - But not a sufficient condition

Classical Problems of Synchronization

- Bounded-Buffer Problem
- Readers and Writers Problem
- Dining-Philosophers Problem
- Sleeping Barber Problem

Bounded-Buffer Problem

- Shared buffer with N slots to store at most N items
- Producer processes data items and puts into the buffer
- Consumer gets the data items from the buffer
- Variable empty keeps number of empty slots in the butter
- Variable full keeps number of full items in the buffer

Bounded Buffer – 1 Semaphore Soln

- The structure of the producer process

```
int empty=N, full=0;
do {
   //   produce an item
  wait (mutex);
        if (empty> 0){
                 //  add the item to the  buffer
           empty --; full++;
        }
  signal (mutex);

} while (true);
```


Bounded Buffer – 1 Semaphore Soln

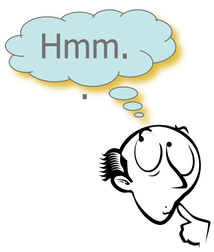
- The structure of the consumer process

```
do {

     wait (mutex);
         if (full>0){
            //  remove an item from  buffer
            full--; empty++;
         }
     signal (mutex);

     //  consume the removed item

} while (true);
```

consume non-existing item!

Summary

- Deadlocks
  - Deadlock Characterization
  - Resource Allocation Graphs
- Classic Problems of Synchronization
  - Bounded Buffer



- Next Lecture: Deadlocks - II
- Reading Assignment: Chapter 7 from Silberschatz.

Acknowledgements

- "Operating Systems Concepts" book and supplementary material by A. Silberschatz, P. Galvin and G. Gagne
- "Operating Systems: Internals and Design Principles" book and supplementary material by W. Stallings
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